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THE IRRIGATION ASPECTS OF GROUND-WATER DEVELOPMENT

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IRRIGATION AND DRAINAGE DIVISION

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THE IRRIGATION ASPECTS OF GROUND-WATER DEVELOPMENT

H. R. McDonald, A.M. ASCE*

SYNOPSIS

The advantages of coordinated use of surface and ground water for irrigation have not been fully realized in the planning and operation of irrigation projects. Generally because of transit losses, farm waste, and deep percolation, only about one-half of the water diverted from streams is used by crops. Significant quantities are commonly used nonbeneficially in poorly drained areas or along natural stream channels. This discussion points out the advantages of ground-water pumping to reduce losses, to prevent or reduce drainage problems, and to irrigate additional lands where the water is of suitable quality and aquifer characteristics are favorable for development of large-capacity wells.

INTRODUCTION

Early irrigation development in the United States was based almost exclusively on the use of surface water, first, by direct river diversion and later with regulation by upstream storage reservoirs. During the last half century, many of the most economical reservoir sites have been developed for power, irrigation, flood control, or other purposes. Millions of dollars have been justly expended and yet nature has provided us with reservoirs of far greater total capacity than all the reservoirs man has built. They are awaiting our use or abuse. We are doing both but unfortunately we have not learned to use them to maximum advantage.

The following discussion points out the methods and potential advantages of coordinated use of ground-water and surface-water storage.

Ground water and surface water are intimately related. In fact, a particle of water, from the instant it falls on the ground, may change from one form to the other dozens of times before it reaches the ocean. Practically all of the fair-weather flow of streams represents ground-water discharge, the overflow of the ground-water reservoir temporarily held in storage.

Historical Development of Irrigation

Modern ground-water irrigation development of the magnitude as it exists today had its beginnings in the United States about the turn of the century. Artesian basins, where water supplies could be developed by natural flow, represented the first significant use and to the layman who knew not whence it came, the supply was considered inexhaustible, but with the drilling of more and more wells, the flows began to diminish and he became concerned. This concern led to the study of artesian basins by various state and federal authorities. It was then that modern ground-water hydrology was born. First attention was given to the West, to the arid regions, because it was here that water supplies spelled the difference between life and death. Surface supplies

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were meager and unreliable and the value of a perennial supply, even though limited, was recognized.

In the early stages of development, little was known about the construction and development of wells. The importance of ground water and the frequency of well failures led to the investigation of the causative factors and theoretical inquiry of the movements of underground waters. One of the earliest of these comprehensive investigations was the work of Slichter reported in a paper entitled "Theoretical Investigation of the Motion of Ground Waters," published in the Nineteenth Annual Report of the U. S. Geological Survey in 1899.

Giving impetus to ground-water development was the perfection of the internal combustion engine and the improvement of the centrifugal pump. Better methods of drilling and finishing wells enabled the production of more water from a single well and at less cost. Thus, the stage was set for modern methods of ground-water irrigation.

The development of ground water for municipal and industrial use was no doubt largely responsible for technological improvements in the design and construction of wells, pumps, and motors. The high unit value of ground water and its advantages for municipal and industrial use provided not only the incentive but also the funds necessary to realize these improvements.

The development of the vertical turbine pump, the well screen, dependable electric motors, and low-cost electrical energy have all given added impetus to the growing use of ground water.

In 1950, the U. S. Geological Survey(1) estimated the total water use in the United States as follows:

	Acre-feet per year (millions)	Percent of total
Irrigation	84.0	44.2
Industrial	86.2	45.4
Municipal	15.7	8.3
Rural, other than irrigation	4.0	2.1
Total	189.9	100.0

The total industrial use includes water for cooling and other purposes where the water is essentially unchanged in quantity of quality.

The total use of ground water for irrigation is difficult to estimate. In only a few areas are reliable data available, and even in these areas the quantity pumped changes significantly from year to year with the increase or decrease in acreage irrigated and with the increase or decrease in annual precipitation. In many areas, ground water is used as a supplement to surface supplies, and the amount used depends to a large extent on the quantity of surface water available.

In 1945, the U. S. Geological Survey (2) estimated the total use of ground water in the United States as follows:

	Acre-feet per year (millions)	Percent of total
Irrigation	11.2	50.2
Industrial	5.6	25.0
Municipal	3.4	15.2
Rural, other than irrigation	2.2	9.8
Total	22.4	100.0

In 1950, the Survey revised its estimate of the use for irrigation to 16.8 million acre-feet per year. Based on reported data from various sources, it is estimated that the present (1954) use of ground water for irrigation is in excess of 25 million acre-feet per year in the 17 western states. Data on pumpage for irrigation in the more humid portions of the United States are almost wholly lacking. However, the limited data available indicate that even in humid areas the use of ground water for irrigation is profitable for growing high quality specialty crops and will be more extensively used as experience is gained.

The use of ground water for irrigation is vital to the agricultural economy of many of the western states, especially Arizona, Arkansas, California, Colorado, New Mexico, and Texas. With the possible exception of Arkansas, the total pumpage in each of the above exceeds 1 million acre-feet per year.

Use of Ground Water in California

California leads all other states in the use and development of ground water. It is estimated by Simpson(3) that the total gross pumpage of ground water in California in 1950 was more than 10 million acre-feet, including municipal and industrial use. It is assumed that for practical purposes, the small quantities used for municipal and industrial purposes would not significantly affect the estimated total use. This usage is broken down by Simpson into seven major hydrographic areas as follows:

Area	Estimated average pumpage (acre-feet)
South Coastal Area	1,500,000
Colorado Desert	100,000[A]
Lahontan Basin	150,000
Central Coastal Area	600,000
San Francisco Bay Area	300,000
North Coastal Area	50,000
Central Valley	8,000,000
Total	10,700,000

A Pumpage for drainage only

Ground-water pumpage has been concentrated in areas of deficient surface supplies, particularly in the South Coastal area and in the San Joaquin

Valley. Continued overdraft has been practical only because of the large storage capacity of the ground-water basins. Even with the large storage available, serious problems are arising. Along the coastal areas, the intrusion of sea water is becoming increasingly serious. In some parts of the San Joaquin Valley, pumping lifts are increasing and economic conditions may largely determine the length of time the present rate of overdraft can be continued.

The coordinated use of surface and ground-water supplies for irrigation probably has been given more consideration in the Central Valley of California than elsewhere. In the Upper San Joaquin Valley area, surface supplies for many years have been insufficient to meet the requirements, and ground-water pumping has been relied upon. In some areas, crop requirements were met wholly by ground-water pumping. Such pumping has been largely from ground-water storage, and the tremendous quantities of water pumped without completely dewatering the most permeable aquifers is evidence of the vast storage capacity of the ground-water basins. Early reports recognized that without development of new water supplies, much of the productive area would necessarily be abandoned. Thus about 1930, the State Water Plan envisioned the diversion of surplus Sacramento River flows to the lower portions of the San Joaquin Valley, and by exchanging San Joaquin flows with the imported water, additional surface supplies could be made available to the higher lands in the San Joaquin Valley. With the execution of the exchange contract and the construction of Shasta Dam and the Delta-Mendota Canal by the Bureau of Reclamation, U. S. Department of the Interior, additional water supplies were potentially available for use on Upper San Joaquin Valley lands. However, not until the construction of Friant Dam and the Friant-Kern and the Madera Canals were significant water deliveries made. Under the proposed plan of operation, ground-water pumping will be utilized to the maximum practical extent, and additional supplies of surface water will will be available. So far as possible, a balanced surface and ground-water supply will be used to meet irrigation and municipal demands. The availability of an average of about 1,500,000 acre-feet of additional surface water to the east side of the South San Joaquin Valley through the facilities of Friant Dam and appurtenant distribution system should prove effective in satisfying the deficiencies in water supply to areas now in production. The additional ground-water recharge and reuse of return flows resulting from the application of the 1,500,000 acre-feet of new water will probably increase the total available from the importation to an average of more than 2,000,000 acre-feet.

Similar plans are underway for augmenting the water supply of the west side of the South San Joaquin Valley. In the San Luis area, nearly 500,000 acres are irrigated wholly by ground-water pumping. Pumping lifts are steadily increasing, and it has long been recognized that importation of surface supplies would be required if the economy of the area is to be stabilized or expanded. Irrigable lands in this area total nearly 1,000,000 acres. The Bureau of Reclamation is currently supplying about 300,000 acre-feet of surface water annually to the west side of this valley from the Delta-Mendota Canal in addition to approximately 1,000,000 acre-feet to the lands below Mendota Pool under the terms of the Exchange Contract. Plans now being studied include the construction of San Luis Dam and distribution system which will obtain water from the Sacramento River, utilizing the off-peak capacity abailable in the Delta-Mendota Canal and Tracy Pumping Plant. Storage would be in San Luis Reservoir. Here, also, the use of surface-water

and ground-water storage would be coordinated to obtain the maximum practical quantity of water.

Use of Ground Water in Arizona

Although the use of ground water for irrigation in Arizona is only about one-half that of California, it is no less important to the economy of the area. For the past several years, the 600,000 acres irrigated in the Salt River Valley area (including Pinal County) have received the greater portion of their water supplies by ground-water pumping. In 1951 [4], the ground-water pumpage in this area exceeded by almost four times the surface water diverted at Granite Reef Dam. The total area irrigated has increased from 436,000 acres in 1946 to 590,000 acres in 1951, and represents about one-half the total irrigated area in Arizona. During the same period, the number of wells increased from 850 to about 1,500. From this, it is apparent that the ratio of increase in number of wells, 75 percent, is greater than that of the irrigated acreage, which is 35 percent. It may be concluded that yields of older wells have diminished, as the water table has declined and the more productive aquifers have become unwatered. Consequently, new and deeper wells have had to be drilled, not only for irrigation of new lands, but to compensate for the decreased production of the older wells.

Smaller quantities of ground water are pumped for irrigation in other basins delineated by the U.S. Geological Survey. The table below indicates the basin and the estimated pumpage in Arizona during 1951 and 1953:

County	Area	Pumping in 1,000 acre-feet	
		1951	1953
Cochise	San Simon, Willcox and Douglas	96	145
Graham	Safford Valley	125	120
Greenlee	Duncan Valley	33	30
Maricopa	Queen Creek, Salt River Valley	2,020	2,498
Pima	Part of Santa Cruz Basin	240	380
Pinal	Santa Cruz and Gila Basins	1,030	1,400
Santa Cruz	Part of Santa Cruz Basin	30	27
Yuma	Gila Basin	127	151
		3,701	4,751

When the amount of water pumped greatly exceeds the quantity of recharge to any basin, it is commonly referred to as "mining," the connotation being that in large measure the water pumped will never be replaced. Studies made by the U. S. Geological Survey in cooperation with the State of Arizona have shown conclusively that most of the water pumped in recent years has been "mined." High agricultural prices, highly efficient pumps and motors, and low-cost power and decreases in surface supplies resulting from drouth conditions are, no doubt, responsible for the large increase in ground-water pumping during the last few years. This has occurred in spite of the fact that pumping lifts have steadily increased.

There is little doubt that the future of the highly developed agricultural

economy in the Salt River Valley Basin, including Pinal and Maricopa Counties, is dependent upon the importation of additional supplies of surface water. Continued overdraft of the present magnitude cannot long be maintained even from a ground-water basin of such large capacity. The Bureau of Reclamation has made a comprehensive study of the means by which the importation of additional water could be made into the area. This study proposes the diversion of water from the Colorado River and, by a pump lift of several hundred feet, delivers it to a point near the existing Granite Reef Dam. Thus, by exchange with water now originating upstream, large areas would be furnished a supplemental water supply. The dispute over water rights and the interpretation of the Colorado River Compact is now before the U.S. Supreme Court.

Shortly after the construction of Roosevelt Dam, about 1910, on the Salt River, water levels within the project which is served by river diversions began to rise, and by 1920 about 31 percent of the Salt River Project area had a water table depth of less than 10 feet, and in about 65 percent of the area the depth to the water table was from 10 to 50 feet. Because of ground-water pumping, first for drainage and later for water supply, the depth to ground water in 1945 was less than 10 feet in only 0.2 percent of the area and was between 10 and 50 feet in about 55 percent of the area. Water levels in areas served wholly by ground-water pumping have declined at a much more rapid rate, and pumping lifts in excess of 300 feet are not uncommon.

Use of Ground Water in Texas

Irrigated acreage in Texas expanded from slightly more than 1,000,000 in 1940 to over 3,150,000 acres in 1950 (5), the increased acreage being served principally by ground-water pumping. Nearly two-thirds of the total irrigated area is located in the high plains. About 600,000 acres are irrigated in the lower Rio Grande Valley and almost an equal amount in the coastal Prairie rice-growing region, although these areas utilize surface water supplies to a large extent. Total ground-water pumpage for irrigation in the Southern High Plains during 1951 was about 2 million acre-feet, but because of drouth conditions prevailing in 1952, pumpage was about 3.7 million acre-feet. As shown in Figure 1, the number of irrigation wells in this area has increased from about 2,000 in 1940 to over 18,000 in 1952.

In the High Plains area where irrigation is practiced almost exclusively by ground-water pumping, average pumping lifts in 1949 were about 110 feet, the maximum being somewhat more than 250 feet. The principal aquifer in this area is the Ogallala formation, a heterogeneous mixture of gravel, sand, silt, clay, and caliche, varying from place to place as to sorting and cementation, as well as permeability. The average thickness of the Ogallala formation in the Amarillo, Lubbock, and adjacent areas is about 210 feet and has been estimated to contain 150,000,000 acre-feet of ground water in storage, of which about 100,000,000 acre-feet are within 200 feet of the land surface.

Use of Ground Water in Colorado

Considerable ground-water development for irrigation has occurred in Colorado, principally in the Arkansas, Rio Grande, and South Platte River Basins. In these areas, ground-water pumping is mainly to furnish supplemental water, though considerable acreages in some of the tributary valleys rely entirely on ground-water pumping for their supply.

Recently, somewhat localized but intensive development of ground water

has occurred in the plains areas of eastern Colorado. In 1952, more than 100 wells had been drilled, which provided a full supply to about 6,000 acres. Development of ground water in this area is moving forward at a rapid pace, as shown by Figure 2. Although a relatively small area is now irrigated in this manner, large areas are susceptible of development, being underlain by the Ogallala formation and having sufficient saturated thickness to permit the construction of large-capacity wells. Recharge to the ground-water reservoir is very limited and pumping is almost wholly from storage.

Development of the San Luis Valley artesian basin in southern Colorado began about 1890, and it has been estimated that more than 7,500 wells have been drilled to date. Most of these wells are of a small diameter and are cased only a few feet below the surface. Consequently, frequent cleaning is required to keep them open, and undoubtedly many of the casings have collapsed and the wells no longer flow at the surface. Recently, several large irrigation wells have been drilled and pumping equipment installed. Total ground-water discharge by pumping or artesian flow during 1952 was estimated by the U. S. Geological Survey to be about 480,000 acre-feet.(6)

The total area irrigated in Colorado, according to the 1949 agricultural census, was about 3,200,000 acres. It is probable that during 1952 total ground-water pumpage for irrigation was between 1,500,000 and 2,000,000 acre-feet.

Use of Ground Water in Other Areas

At present, Nebraska has about 900,000 acres irrigated, of which about one-fourth is supplied almost entirely by ground-water pumping. The most intensively pumped area lies in the Platte River Valley between Kearney and Grand Island. Based on a survey recently made by the Omaha World Herald, there are about 4,000 irrigation wells in Lincoln, Dawson, Buffalo, and Hall Counties. It is estimated that about 400,000 acres in Nebraska are irrigated wholly or in part by ground-water pumping from a total of about 8,000 wells. The total quantity pumped at present is probably in the neighborhood of 600,000 acre-feet annually.

Although the 1949 census indicates that Kansas has only about 140,000 acres under irrigation, there is a large potential ground-water development from the Ogallala formation in the western part of the state. There is considerable ground-water pumping, at present, in local areas, and this can be expected to increase if prices remain at their present level.

It is significant to note that irrigation is not confined to the so-called "arid" states. Supplemental irrigation is now practiced in every state east of the 100th Meridian. The increased interest in irrigation is evidenced by the fact that the area receiving supplemental water increased from 780,000 acres in 1940 to 1,500,000 acres in 1950, or an increase of about 95 percent, while in the so-called "arid" and "semiarid" states, the increased acreage was only about 22 percent.(7) The advantage of irrigation in humid areas stems from the fact that, although the total annual rainfall may be adequate, the monthly distribution is such that crops frequently suffer from water shortage during a critical part of the growing season. The value of supplemental irrigation in such areas has been studied by many of the state experiment stations in the 31 states east of the 100th Meridian. The advantages of the development of ground-water supplies in favorable areas are evident. Ground-water supplies usually are not vulnerable to evaporation losses and,

hence, are available when streams and farm ponds reach their low stages during dry periods.

The Concept of Ground-water Storage, Recharge, and Discharge

Since our ground-water resources are a significant portion of our total water supply for irrigation and other uses, why have we, as a nation, not given more thought to their development and utilization? There are several reasons. In the first place, the concepts of storage, recharge, and discharge are not well understood by the average engineer. Ground water is largely hidden from view, is difficult to measure, and in some respects behaves unlike surface water. Studies of ground-water reservoirs depend, in a large measure, on indirect evidence obtained from geological and engineering studies; yet, ground water forms a significant part of our total water resources, and as we reach the limit of development of surface water, we must look more and more to ground-water sources for additional supplies. Fortunately, the science of ground-water hydrology has provided us techniques to use which were not available 50 years ago. We have learned how to estimate the capacity of nature's reservoirs, how to determine the inflow, outflow, and perennial yield. We know that ground-water storage, if properly used, will provide water that is essentially free from silt and bacteria and of relatively uniform temperature and chemical composition.

Likewise, advances in the design and construction of wells, pumps, and powerplants have provided the means by which the water stored in these natural reservoirs can often be utilized economically. Low-cost electric or diesel power has made possible the recovery of millions of acre-feet of water that would otherwise not have been available.

In some respects, ground-water reservoirs are similar to surface water reservoirs. They have a given capacity and must have a recharge and a discharge. The reservoirs are often irregular in shape and intricate in their construction, but their location can be mapped and their structure determined. The hydraulic characteristics of the aquifers comprising the reservoirs can be accurately determined with respect to recharge, discharge, storage, and movement. These processes involve laws of fluid mechanics which obey the principles of physics but which have little significance in the hydraulics of surface water. The most efficient operation and use of these reservoirs can be accomplished by the practical application of the knowledge developed by these scientific methods of investigation.

One of the most difficult problems in regard to any ground-water development is how much of the water pumped is taken from storage and how much is supplied from surface sources. The latter quantity is dependent on the size and location of the intake area, the permeability of the surficial material, and the amount and distribution of the water available for recharge. The "stage" of the reservoir must be determined by measuring the elevation of the water tables in wells. Since the water surface is not a plane, as in a surface reservoir, many wells must be used. If the reservoir is full, the water available for recharge will be rejected, and thus the potentialities of the reservoir are not being realized.

All ground-water reservoirs have some natural discharge. Withdrawals from the reservoir will either reduce the natural discharge, increase the natural recharge, or reduce the storage. The amount of water that may be perennially withdrawn from the reservoir is dependent only on two factors: (1) the reduction of the pre-existing discharge, or (2) the increase in recharge

over what has occurred historically. This does not imply that water may not be withdrawn from storage for 1 year or even for several years, provided that accretions to storage are made such that the average discharge is equal to the average recharge. The development of artesian basins is often limited in an attempt to maintain artesian pressures such that flowing wells may be obtained. This means that only a small fraction of the total storage capacity of the reservoir is being utilized.

In some instances, the perennial yield of the reservoir is limited by the capacity of the aquifer to transmit water rather than the amount of water available for recharge. The aquifer thus serves as a conduit from the recharge area to the discharge area, although it may have some of the characteristics of both a reservoir and a conduit.

For this reason, the manner in which a ground-water reservoir will operate is determined largely by the characteristics of the aquifer of which it is comprised.

In studying the effects of pumpage or withdrawals from a ground-water reservoir, it has often been found useful to operate the reservoir through a critical period much as is commonly done in determining the hypothetical function of a surface reservoir. In such instances, the capacity and the recharge must be known within a reasonable degree of accuracy.

Potential Salvage of Water Supplies by Coordinated Use of Surface and Ground Water

When surface water is diverted for irrigation use, a significant portion percolates below the root zone of plants, and with suitable drainage conditions, in due course of time, finds its way back to natural or artificial drainage channels. This water, together with farm waste, is usually termed return flow. Where the physical conditions are suitable, such water may be rediverted to additional lands and used for irrigation purposes. In instances where this water must be carried in natural drainage channels for long distances before rediversion, quite often the channels become choked with tules, cattails, and other water-loving vegetation termed "phreatophytes" which sometimes use a large part of the water available. In the southwestern states, a plant known as salt cedar or tamarisk (Tamarix gallica) is often found. This plant, introduced from the Middle East about the turn of the century, often infests deltaic deposits at the head of reservoirs, along streambanks, and drainage channels. The U. S. Geological Survey, in an investigation of the Safford Valley in 1943-1944 found that these plants used from two to three times as much water as required by most crops.

The water used by these plants varies as the depth-to-water, temperature, and as the volume-density of growth. Poorly drained areas, such as are found near, or in, almost any irrigation project, provide a suitable environment for these plants. In the aggregate, their total use is no doubt several million acre-feet per year. Although their total use is great, a difficult problem is presented when an attempt is made to recover this water economically. It is believed that by proper coordination of surface and ground-water reservoirs, a significant amount of the water thus lost could be salvaged in some areas.

Inasmuch as phreatophytes are commonly found in poorly drained areas, it is possible that large quantities of water could be salvaged by lowering the water table by ground-water pumping, if suitable aquifers occur. Peak demands for irrigation occur simultaneously with maximum use by

phreatophytes, and continuous pumping during the growing season would be effective in reducing the water available to the phreatophytes.

In instances where natural streams flow through phreatophyte-infested areas, channelization has made possible significant salvage by lowering the water table within the area and by reducing the travel time of upstream reservoir releases or flood flows. For example, significant water salvage had been demonstrated by this means in the Middle Rio Grande Valley of New Mexico, even though construction has not been completed.

A situation similar to that in the Middle Rio Grande Valley also exists in the Pecos River Basin. Because of more limited runoff in the Pecos River Basin, the nonbeneficial depletion presents a more pressing problem.

McMillan Reservoir was constructed on the Pecos River about the turn of the century to provide storage for the Pecos Irrigation Company, the predecessor of the Carlsbad Irrigation District. McMillan Reservoir had an original capacity of about 80,000 acre-feet but has been depleted by sedimentation so that its present capacity is only about 37,000 acre-feet. In addition, leaks have developed in the reservoir area and its effectiveness further reduced. After various studies of the possibilities for the enlargement and rehabilitation of McMillan Dam, it was recommended that a new dam be constructed farther upstream at the Alamogordo site. This was authorized by the President in 1935 and construction completed in 1937 by the Bureau of Reclamation. At about the same time, the Red Bluff Reservoir was constructed farther downstream for the benefit of Texas interests. Meanwhile, phreatophytes consisting almost entirely of salt cedar gained a foothold in the Lake McMillan delta deposits. The phreatophytes spread rapidly upstream and provided an effective means of keeping the sediment out of the reservoir; apparently at that time no one realized how much water they were consuming.

Because of the interstate problems involved, a compact commission was first appointed about 1925, but it was not until 1948 that the Pecos River Compact became effective. The compact provided among other things that New Mexico's depletion of stream flow by man's activities would be limited to that existing as of 1947, but would not be responsible for additional depletions resulting from natural causes. The Pecos River Commission was established to administer the compact.

Studies by the engineering advisers to the Pecos River Commission and others have revealed some startling facts. The phreatophytes have spread rapidly and their water consumption has been estimated (Figure 3). Since being introduced into the area about 1912, they covered an area of some 14,000 acres in 1939, about 27,000 acres in 1946, and by 1953 assuming the same rate of increase, about 36,000 acres. These phreatophytes have a potential ability to consume between 140,000 and 170,000 acre-feet of water annually. In effect, these plants are robbing the water supply of the river. Although it is obtained almost entirely from the ground-water reservoir, ground-water depletions are restored by river flows before they continue downstream. This use has also had the effect of further concentrating the soluble salts in the Pecos River flows, which at best are somewhat saline, largely as a result of brine springs in the vicinity of Malaga Bend. To complicate the problem further, ground-water pumping from shallow aquifers was started about 1927 in the area between Roswell and Artesia. Although the New Mexico State Engineer has closed the area to additional pumping, it has no doubt decreased the base flow of the Pecos River.

If the curve shown in Figure 3 is extended to 1965, assuming that the present rate of spread of phreatophytes is maintained, it is evident that their

potential consumptive use would be about two-thirds of the average annual runoff of the river at Artesia, which is about 300,000 acre-feet.

The above example illustrates the intimate relationship of ground water and surface water, and that at least, in some instances, studies of one without the other would be of little value. In this connection, Dixey (8) states: "The study of ground water provides the key to many hydrological problems which are not at first sight directly related to it, and it is particularly important for example in problems of river management. The interrelation of surface water and ground water need further examination; increasing use of the one may result in loss to the other, and the complete use of surface water for irrigation may stop accretion to ground water."

The Problem of Economic Yield

In the absence of legal restrictions and physical limitations, the economics of pumping is usually the determining factor for not only the location but the quantity of ground water pumped for irrigation in arid areas. Water has a higher value for domestic and municipal supplies than for irrigation, and therefore, for these uses more elaborate installations and higher operational costs can be sustained.

Almost without exception, the history of ground-water irrigation development of arid areas demonstrates that where the land resources exceed the water resources, the ground-water reservoirs have been overdeveloped if it were profitable to do so. In some areas, the problems of overdraft have been recognized and appropriate measures taken before development reached the stage where legal control alone would not offer a practical solution. A prime example is the Roswell Artesian Basin in New Mexico. In other areas, such as parts of Texas and New Mexico, legal attempts to control unlimited ground-water pumping have been made, but have been partially successful because aquifer overdevelopment occurred prior to legal control.

A unique problem is presented in such areas as the high plains region, which covers parts of New Mexico, Texas, Oklahoma, Colorado, Kansas, and Nebraska. Annual average recharge from precipitation is limited to perhaps 1/4 inch to 1/2 inch annually, depending on the average precipitation of the locality. Assuming an average recharge of 1/4 inch and an average unit irrigation consumptive use requirement of 1.0 foot, an average of only 1 acre in each 48 acres could be irrigated if the irrigation depletion was limited to the recharge. The question then arises as to the desirability of limiting irrigation by legal restrictions to such a degree, particularly in an area where the quantity of ground water in storage is very large in relation to the recharge. Obviously, if the ground water remains forever in storage, it will be of little economic benefit to the overlying land owners or to the public, but if utilized by "mining," an irrigation economy may be developed and sustained for a given length of time depending on the quantity of water in storage, the extent of development, pumping lifts, etc., say from 30 to 50 years. Such development and utilization of the ground-water storage during that period would be of great value, not only to the individuals involved, but to the state and nation as well. However, many social and economic problems may result from such developments. Permanent improvements such as buildings, roads, and utilities in all probability must ultimately be abandoned and those dependent on irrigation agriculture must seek another means of livelihood, unless, of course, a new source of water can be made available. The resulting social

problems would be similar to those of the early-day mining camps when the ore bodies became exhausted.

In a recent case in the District Court in Lea County, New Mexico, the State Engineer testified to the effect that he considered that the waters of such a basin were fully appropriated when there was enough water remaining in storage to supply the prior appropriators a reasonable quantity of water for a reasonable length of time. His testimony was to the effect that there are no means of utilizing water in storage in such a way that appropriators will have a right to the use of that water in perpetuity. In a recent speech, Mr. George Harris, attorney for the New Mexico State Engineer, expressed the opinion that an irrigation economy should last for at least 40 years, and that appropriations for the use of ground water should be based on studies using this criteria.

Legal Aspects of Ground-water Pumping for Irrigation

Laws relating to the use of ground water are generally based upon and similar to those governing the use of surface water. Basically, two major doctrines have been in use in the United States—the common law doctrine of riparian rights and the doctrine of prior appropriation. As applied to ground water, the riparian right is based on the ownership of land overlying a water-bearing formation. The right is sustained even though it is not used. The doctrine of appropriation recognizes that "the first in time is the first in right," and generally is limited to the quantity of water that is used beneficially. Also, the appropriative rights is usually forfeited if not used for a specified period of time.

Attempts have been made by the court in some instances to distinguish between "percolating ground water" and "ground water flowing in definite underground channels." "artesian water," "diffused surface water," etc., and to apply different regulations based on those distinctions. Because this distinction is not based on scientifically defensible facts, it has caused much confusion. Regarding this, Fiedler and Thompson(9) state: "We believe, as a matter of fact, that from a scientific point of view, such an elaborate classification of ground water is neither justified nor necessary. All water in the part of the earth known as the zone of saturation is purely and simply ground water, moving according to certain well recognized laws of physics."

Because of the competition for limited water supplies under the riparian doctrine, the New Hampshire State Supreme Court in a decision rendered in 1862, ruled that a man's right to use water percolating under his own land is limited by the corresponding right of his neighbor. This has since become known as the American Rule of Reasonable Use. The California Supreme Court further modified the American Rule and held that not only must the use be reasonable, but it must also be correlated with the uses of others and in times of shortage each should receive a fair and just share.

At present, at least 15 states have some form of ground-water law based on the appropriation doctrine, and about 6 states apply the American Rule of Reasonable Use to the riparian doctrine. In all the other states, the common-law doctrine is followed.

Just as disputes have arisen between water users in the same state, likewise disputes have arisen between states. The earliest disputes pertained to territorial boundaries, and agreements were reached by compact, the first about 1780. Since 1789, the compact method has been used extensively, dealing with problems of flood control, navigation, fishing, stream pollution

abatement, vehicular tunnels, municipal water works, and port facilities. In the last half century, many compacts dealing with surface-water allocation have been negotiated between two or more of the western states. So far as is known, none of these pertain to the use of ground water specifically, though the concept of stream depletion upon which some compacts are based would include stream depletions as a result of ground-water pumping.

In recent years, more emphasis has been given to the coordinated operation of river systems. Experiences in the Tennessee Valley, the Missouri and Columbia Basins, and elsewhere have demonstrated the advantages of coordinated river operations. However, lacking some overall governing body composed of representatives of the interested parties, such coordination would be difficult or impossible to obtain. The Compact Commission method of approach would appear to most nearly meet these needs. In the past, it has generally been considered that once a compact has been negotiated, it is sufficient except for rigid enforcement of its terms. In view of the ever-changing physical, economic, and social conditions, there may be advantages if compacts merely established operating principles with enough flexibility to permit operating rules to be modified by the Commission when studies showed it would be beneficial to all parties concerned. Such a concept would require continuous study by the Compact Commission of changing physical and economic conditions within the basin as a whole, but it would provide a flexible mechanism capable of meeting the changing conditions. The increasing use of ground water for irrigation in some western river valleys, the sedimentation of reservoirs, and the constantly changing water quality emphasize that if full benefit is to be realized from the available water resources, it cannot be attained under a set of inflexible rules.

The Potentialites of Ground-water Development in Relation to Agriculture

The expansion of agriculture in the arid and semiarid western states is largely dependent on two factors: (1) the importation of water to shortage areas from regions having a surplus, and (2) the judicious development and use of ground water.

It would be difficult indeed to predict the effect of changing economic and social conditions on the feasibility of transbasin diversion projects. In the final analysis, each must be evaluated in the light of prevailing conditions at the time they are studied.

In some shortage areas, transbasin diversions may not be practical or economical and increased agricultural development may depend on the reduction of nonbeneficial consumptive uses. Areas having a shallow water table and high nonbeneficial uses may present an opportunity for salvage by ground-water pumping. Because of the deterioration of water quality resulting from irrigation use, allowance should be made for adequate outflow from the basin to maintain the salt balance.

The future of irrigation in humid areas and especially the use of ground water for irrigation is certain to receive more attention in future years than it has in the past. For example, the increasing demand for high-value specialty crops by the frozen food industries will stimulate the search for a reliable source of supplemental water as drouth insurance. Ground water, if available in suitable areas, will admirably fulfill this need.

CONCLUSIONS

The rapidly expanding development of ground water for irrigation indicates that its use is becoming increasingly important in the utilization of our total water resources. Coordinated development of surface and ground water offers possibilities that should be considered in the planning of irrigation projects if maximum development is to be attained.

Ground-water developments, if properly planned, will often permit the serving of more land than could be supplied from surface sources alone, and at the same time may prevent or greatly reduce drainage problems inherent in most irrigation projects.

Recent advances in the design and construction of wells, the availability of cheap electrical power, and the increasing demands for specialty crops have given impetus to the development and use of ground water for irrigation.

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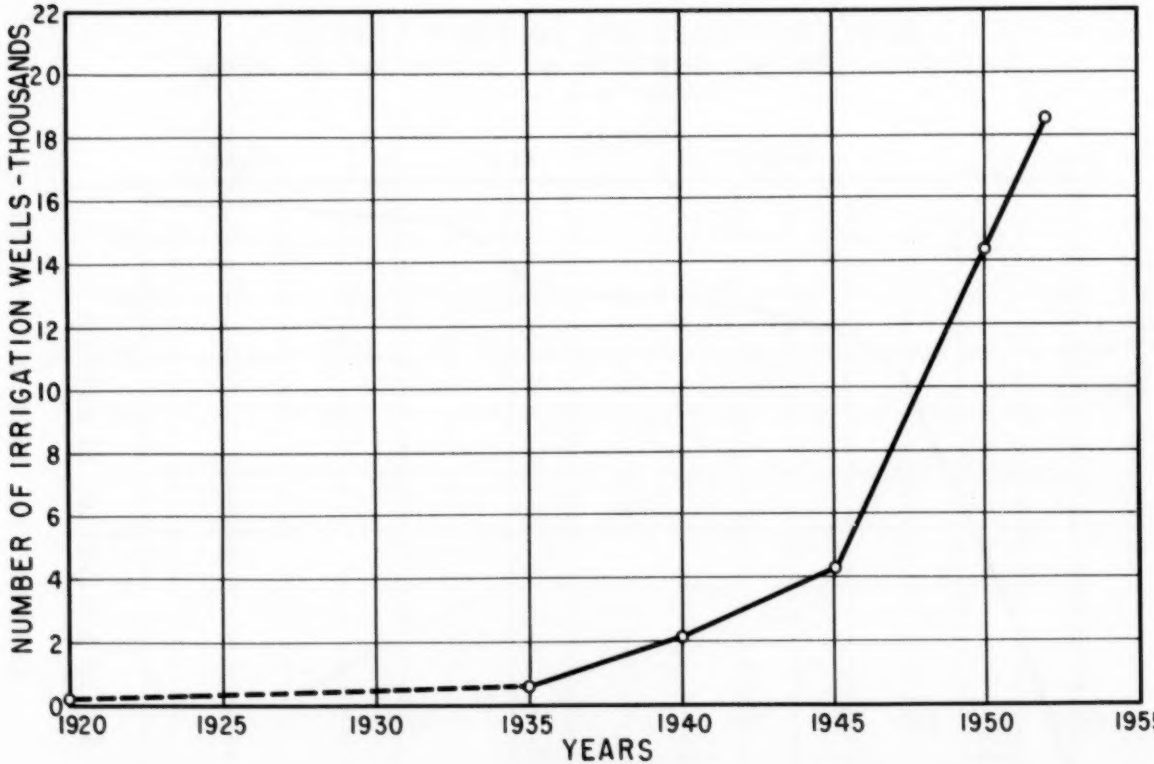

FIGURE I

RATE OF INCREASE IN NUMBER OF WELLS IN THE SOUTHERN HIGH PLAINS OF TEXAS

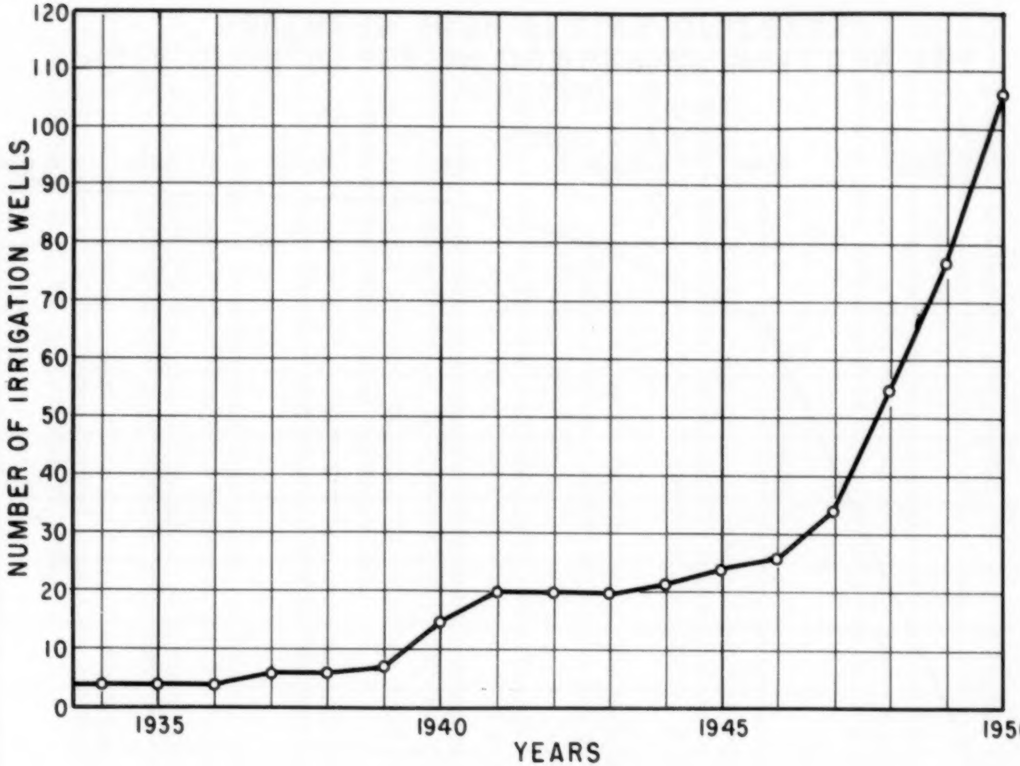

FIGURE 2
RATE OF INCREASE IN NUMBER OF WELLS IN THE PLAINS AREA OF EASTERN COLORADO

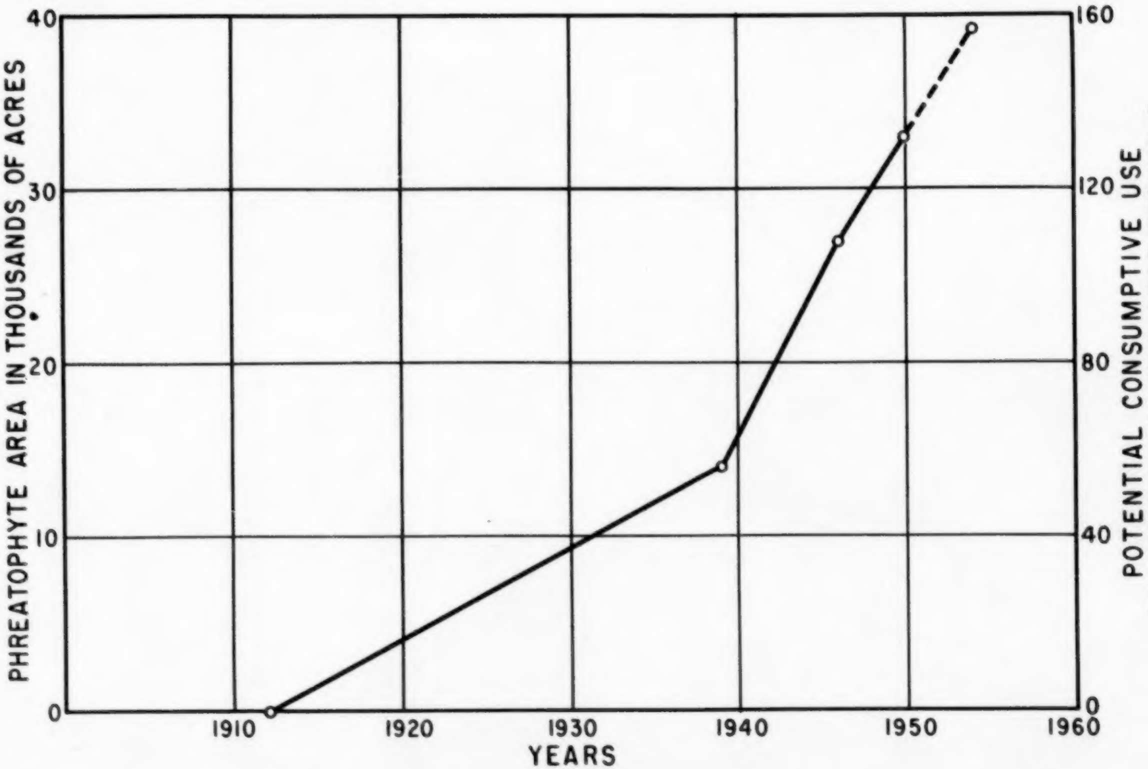

FIGURE 3

RATE OF INCREASE OF PHREATOPHYTE AREA AND POTENTIAL CONSUMPTIVE USE IN THE PECOS RIVER BASIN, NEW MEXICO